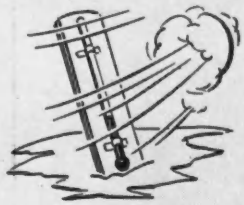
Some of the whens, whats and whyfors of concreting in the winter months



A Guide to

WINTER CONCRETING

AROUND THIS TIME of the year Northern concrete contractors start thinking wistfully of their fortunate Southern friends, for it is now that preparations must be made for the cold weather ahead. Perhaps some solace can be found in the fact that tests have shown concrete placed at low temperatures above freezing and not allowed to freeze develops higher strength and greater durability than concrete placed at high temperatures.

At any rate, the first matter to decide is whether winter concreting will prove economically feasible in your own case. Factors affecting your decision will probably include the following: length and severity of cold weather; contracted construction schedules; profit margin; availability of equipment, labor and supplies; and the type of construction and stage of hardening at which freezing temperatures can be expected.

There was a time when the first freeze heralded the close of the concrete construction season. Today, with accelerated building programs the rule, contractors can hardly afford to close shop for four months. Fortunately, several developments which have originated or become popular in the last decade make winter activity easier and more economical. Among these are air-entraining agents, calcium

Some Hints for Cold Weather Concreting

1. More cement in the mix will keep strengths up during cold weather.
2. Try to arrange with the architect or engineer for monolithic floor finishes to be placed after the structure has been enclosed. Putting a protective covering on would tend to mar the finish.
3. If floors must be placed before a multi-story structure can be enclosed, support canvas a little above the floor. Then leave holes in the slab (one hole for each 300 square feet of floor area) to allow heat from below to rise through them and warm the top of the floor slab.
4. Easiest way to cure cast-in-place outer walls is to leave the forms in place (use insulation, if necessary) and heat the interior.
5. If the construction site is remote, remember to make provisions for drainage, clearing access roads, services, lot layouts, excavations, water supply, land clearing, material storage and housing.
6. Avoid having steel projecting through the forms. Tests have shown that if as little as 1⅔ percent of an area is composed of projecting reinforcement, there is a resulting heat loss over this area of about 35 percent.
7. Keep forms as dry as possible. Wet forms are much less effective insulation than dry ones.

FILE: WINTER CONCRETING

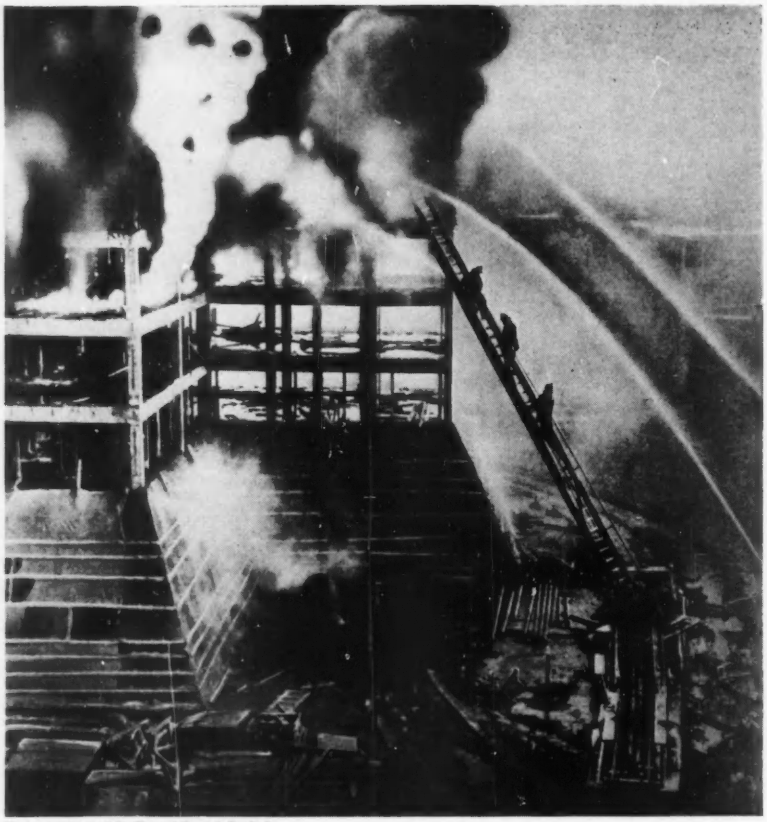


Photo courtesy of H. Wenzel Tent & Duck Co.

The holocaust pictured here resulted from the careless use of open-flame heaters to protect concrete against freezing. A good rule is to keep heat sources at least 10 feet away from canvas enclosures. Enclosures should be flameproofed and round-the-clock watchman service should be provided.

chloride and form insulation.

It takes twice as long for concrete to set up and gain the strength needed for most jobs when the temperature is 50 degrees F. as when it is poured at 80 degrees. Concrete curing stops at a point slightly above 32 degrees; if no freezing occurs, curing will continue when the temperature rises. If the concrete does freeze, however, the chances are it is severely damaged, and the expensive process of tearing it out and repouring must be undertaken. In either case, costly delays are encountered.

Essentially, the basic rule for winter concreting is simply that the concrete must be prevented from freezing before it has cured. The rule turns out to be a little less than simple in application, but fortunately several factors work in the contractor's favor. One is the automatic protection provided by heat of hydration—the heat that is a byproduct of the chemical interaction of cement and water. Since good concrete is extremely dense, it tends to retain this heat as protection against freezing.

Now let's take a look at the various protective techniques which the contractor can employ, classifying them according to the temperature ranges in which they most likely would be used. This classification is not to be construed strictly. Each technique is merely listed at the earliest stage that it would seem logical to employ it under average job conditions. Many in the earlier categories might with good effect be combined with the more extreme measures.

40 Degrees and Above

The ideal temperature for concrete work is about 70 degrees. Considerable latitude can be comfortably taken in stride by concrete; but after the first frost and until the mean daily temperature falls below 40 degrees, the following steps should be taken to protect concrete work.

During this relatively moderate weather, precautions need not be elaborate. Often merely leaving the forms in place will confine the heat of hydration sufficiently to assure continued curing. This may not, however, be sufficient in the case of steel forms. Remember that corners and edges are the most vulnerable areas to freezing, and are consequently the best places for testing to determine the effectiveness of your protection.

The length of time necessary to maintain protection depends somewhat upon the composition of the mix. If it contains an air-entraining agent (and it should for all cold-weather work), protection need be maintained for only 48 hours. No amount of protection will produce non-air-entrained concrete with durability equal to that of air-entrained concrete that has been properly cured. In addition, to get the amount of durability possible in a non-air-entrained mix, it is necessary to protect it twice as long. The extra air spaces, in effect, give the water in concrete room in which to expand when freezing does occur. This accounts for its high ultimate durability and better recovery from freezing that might take place soon after pouring.

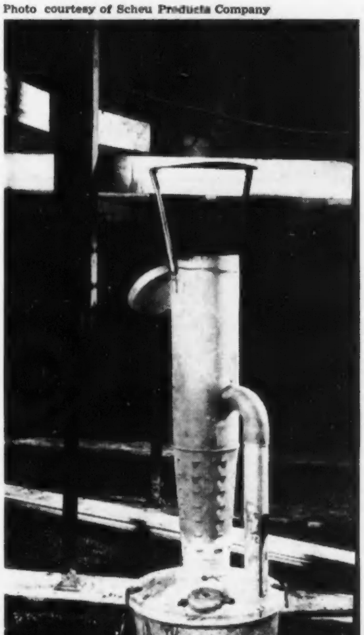
Another additive that plays an important part in winter concreting is calcium chloride. When sulphate resistance is not needed, the addition of one percent of calcium chloride by weight of cement results in (1) acceleration of set; (2) higher early strength; (3) higher ultimate strength; and (4) more uniform curing. If it is

Enclosures enter the winter concreting picture in earnest when the temperature drops below 30 degrees F. Concrete in this multi-story building has been protected against freezing by means of complete enclosure with flame-proofed canvas tarpaulins.

Photo courtesy of Hoosier Tarpaulin Company

Widely used for winter protection of concrete, this type of oil-burning salamander may have an output ranging from 70,000 to 140,000 B.T.U.'s per hour. Space heaters of this type should be so constructed that fuel does not spill out if the units are knocked over.

Photo courtesy of Scheu Products Company



not used, seven days instead of three will be needed at 50 degrees to obtain the same ultimate durability. Remember that calcium chloride is an accelerator and not an anti-freeze. Don't use calcium chloride if other accelerators are used.

30 Degrees and Above

At the onset of colder weather, protection must be provided in earnest. We assume air-entrainment and calcium chloride, but now more is needed. When the mean daily temperature starts falling below 40 degrees for much more than one day, the material in the mix should be heated. This cannot be done indiscriminately.

We've mentioned that properly protected concrete placed in cold weather reaches higher strengths than in warm weather, but the temperature of the concrete should not exceed 80 degrees. If if does, strengths are lowered and the danger of flash set becomes great.

Ideally, the concrete should be in the 70- to 80-degree range. This necessitates heating the mix water and, during colder weather, the aggregate. Experience and complete equipment is needed to blend these various ingredients and come up with the correct mix at the right temperature. The cheapest, easiest and safest way to get this is to rely on your supplier of ready-mixed concrete.

20 Degrees and Above

When the mercury sinks to this level it's time to start using heaters, insulation and enclosures. Naturally, these measures involve greater manpower to set up and maintain and are therefore more expensive than those we've discussed up to this point.

Heaters for concrete work are usually salamanders. It should be made certain that all heaters used are of such construction that the fuel does not spill out if they are knocked over. Also, it would be wise to determine which trade claims jurisdiction over the units to gauge the effect on costs.

Salamanders are valuable items in cold-weather concreting, but they can prove to be dangerous allies if proper caution is not exercised in their use. Since they manufacture a great amount of carbon monoxide, enough vents must be provided to prevent workmen from being overcome. The vents, in turn, must be carefully located to avoid wide

variations in temperature. Heavy concentrations of carbon dioxide from the heaters have a deteriorating effect on the concrete surface. (See CONCRETE CONSTRUCTION, October 1956, page 2.)

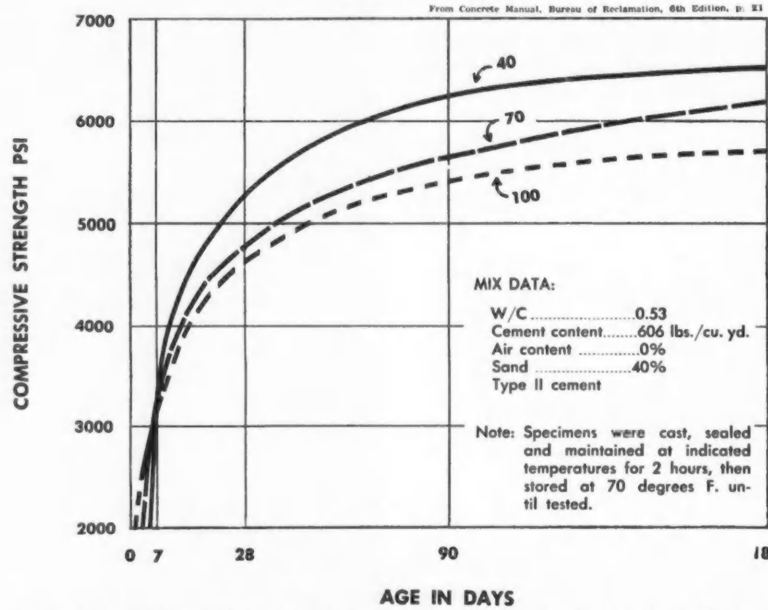
Heaters that increase air temperature without adding moisture to the air have a pronounced drying effect on concrete. Air which has been heated from minus 20 degrees to plus 50 degrees has its absorptive powers increased up to 25 fold. This means that unprotected concrete would soon dry out. This danger can be abated by providing an independent source of moisture, or by means of exhaust steam heating. The latter, however, is usually more expensive to set up. Water curing is generally not needed during cold weather because the absorptive ability of cold air is low; when it is resorted to, care must be exercised to prevent any air leakages in the enclosure that would cause the formation of ice.

Protection from the drying effect of winds and confinement of manufactured heat is offered by the many enclosure materials now available. These materials include wood, canvas, gypsum wall board, fiber insulation board, plywood, sisalkraft, tarred paper and the new plastic sheets. In unformed work, tarpaulins supported on horses or a framework should be set up soon after the pouring operation so that only a small amount of slab is exposed at any time.

Tarps should be arranged so that the heated air is circulated on both the top and bottom of the slabs in multistory buildings. Keep heat sources 10 feet away from canvas enclosures and use only canvas that has been flameproofed. The enclosure, if constructed of a flexible material, must be kept securely anchored to prove effective.

Recently, a great deal of interest has been given to form and slab insulation. (For complete information on this subject, see CONCRETE CONSTRUCTION, February, 1957, page 2.) Development of more rugged backing for the insulation material has widened its popularity considerably. As an example of what can be accomplished with such materials, on a Chicago floor job on which batt insulation was employed, the outside temperature ranged from 13 to 34 degrees. The bottom of the slab was kept at 60 to 65 degrees while the surface of the slab under the batts stayed within the range of 50 to 64 degrees.

Initial Mix Temperature Affects Concrete Strength
(Curing Temperature 70 Degrees F.)



The graph above shows how the compressive strength of concrete drops as initial mix temperature is increased. Mixing temperature should not exceed the 70- to 80-degree range.

The table below shows how the strength of concrete is affected at various ages by the inclusion of 2 percent calcium chloride in the mix.

EFFECT OF CALCIUM CHLORIDE TO INCREASE STRENGTHS AT VARIOUS TEMPERATURES

Type 1 Portland Cement

5½ sacks cement per cu. yd. 2½ to 3½ in. slump

Age at Test	Compressive strength psi — Degrees F. 25	40	55	73
Without calcium chloride				
1 day	35	75	540	1310
7 days	575	1990	3480	4170
28 days	1470	4820	5810	5630
1 year	6350	7190	7540	6670
With 2% calcium chloride				
1 day	185	400	1290	2350
7 days	1795	3230	4280	4610
28 days	3800	4970	5850	5740
1 year	7350	7950	7460	7750

Below 20 Degrees

Many concrete jobs have kept going despite sub-zero temperatures. In these cases, however, costs are high since several or all of the above techniques must be employed. Careful planning and estimating must be undertaken in such instances or profit will take a beating or disappear altogether. So many indirect costs arise during winter operations (for example, starting solutions, extra machine parts, anti-freeze, housing protection for equipment repair work, and cold weather concreting instructions for personnel) that it's an easy matter to overlook some. Such unpredictable items as the manpower efficiency drop in freezing temperatures and greater probability of equipment breakdowns also must be taken into consideration.

The picture is not all black, however. There are some appealing aspects to winter construction. Labor is plentiful during these months and hard-to-get materials are usually more easily obtained. Then, too, many good jobs simply must be undertaken, or continued, at this time. All things considered, cold weather concreting is with us to stay. Whether it turns out to be a blessing, or something else, depends upon the discretion and care of the contractor—and a little, of course, on the good (or bad) behavior of the weather man. END

A DOZEN DON'TS

1. DON'T undertake any winter concreting until you have fully surveyed the situation.
2. DON'T use more than 2 percent calcium chloride by weight of cement.
3. DON'T use calcium chloride where sulphate resistance is needed.
4. DON'T heavily load newly stripped slabs. Concrete gains strength slowly in cold weather.
5. DON'T set salamanders directly on concrete. Localized drying can be extremely harmful.
6. DON'T let heaters go untended. They constitute fire hazards.
7. DON'T expose protected concrete to cold weather abruptly. This is especially true in massive work where heat of hydration can raise the internal temperature up to 70 degrees above that of the surface. This causes cracks.
8. DON'T use unvented heaters without allowing for escape of the carbon dioxide gas they manufacture. This gas reacts with the concrete to cause soft surfaces which hardeners cannot repair.
9. DON'T try to place concrete on frozen soil. Not only is it expensive to keep within an allowable temperature range, but considerable settling will occur when the sub-soil thaws.
10. DON'T forget the wind. Protection that is effective during still weather might prove totally inadequate during periods of high winds. Therefore, take the building site exposure into consideration when planning a job.
11. DON'T neglect to put extra heaters near outside walls during very cold weather. Generally speaking, two average-output salamanders should be placed at each exterior column at temperatures below 20 degrees.
12. DON'T let equipment get dirty or in disrepair during winter. Snow and muddy soil put heavy loads on moving equipment and cold weather is an extra strain on batteries, transmissions and motors.

WINTER CONCRETING — IS IT WORTH IT?

Advantages

1. Labor is usually more readily available during the winter months.
2. Trained crews are kept intact by maintaining a 12-month schedule.
3. Personnel morale and loyalty are higher since there is no seasonal lay-off.
4. Most materials, even scarce items, are easier to come by.
5. Overhead is reduced by keeping equipment in use all year round.
6. Big projects are done in much less time with a continuous schedule.
7. Many large jobs require winter concreting in order to complete the contract on schedule.

Disadvantages

1. Efficiency of workmen is lower during cold weather.
2. Extra cement and/or additives are required. Also expensive cement types.
3. Forms are tied up longer to allow concrete to set and for insulating.
4. Equipment tends to require more attention and accumulate more down time.
5. Extra equipment is needed, e.g., canvas, salamanders, straw, etc.
6. An increased fire hazard exists due to the heating devices needed.
7. Bidding is more difficult since there are more items to consider, and they are harder to assess.

A comparatively recent material to facilitate concreting is blanket insulation enclosed in extra heavy asphalt-coated liners to withstand abuse and exposure. Because insulation of this type remains dry, it performs at highest efficiency.

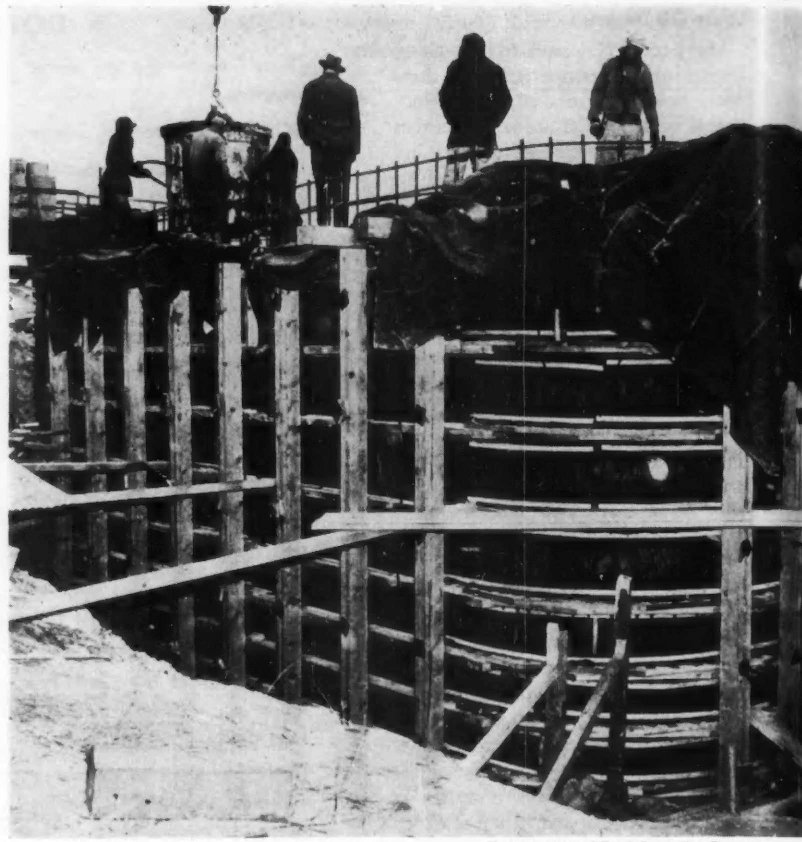


Photo courtesy of Wood Conversion Company

To help you with problems of winter concreting, here is a guide to . . .

Rating the Protective Coverings

ESSENTIALLY, the aim of winter concreting is to keep the cold out and the heat in—at least until the concrete has cured sufficiently to withstand the effects of low temperature without assistance.

The heat that we are trying to retain within the concrete is usually of two natures. First, there is the heat that has been introduced by heating the mix water and/or aggregates. Secondly, heat of hydration adds considerably to the total once it has built up—reaching (when Type I cement is used) a peak about 24 hours after the water and cement have been mixed.

Heat of hydration (a byproduct of the chemical interaction of cement and water) is often spoken of but is seldom pinned down specifically. It has been found that it is more or less constant per foot of concrete regardless of the water-cement ratio. However, its effectiveness in maintaining satisfactory temperatures during cold weather depends greatly upon several factors, including the mass of concrete, surface area and air temperature.

Measurements taken at the center of large masses of concrete placed at 70 degrees F. indicate that a temperature of 160 degrees is reached after three days. This means that 1 pound of cement generates 180 to 190 BTU. Therefore, a cubic yard of 5-sack concrete, which would contain 450 pounds of cement, develops in the first three days approximately 82,300 BTU—a very considerable amount. These figures are based on Type I portland cement.

Combining this with the heat from the warmed water and aggregates of the mix, it can be readily seen that a great deal of the cold-weather problem can be licked by simply keeping this heat within the concrete. The heated mix is effective in providing protection during early curing, and the heat of hydration helps out during the later stages. Of course, the mass of the concrete has a great bearing on the extent to which heat of hydration will serve as protection. The greater the mass and the smaller the surface area, the more effective it becomes.

Many means have been devised to

Enclosures of canvas, polyethylene film, sisalkraft and similar materials should be applied so as to leave a small dead airspace between them and the concrete.

Blanket insulation can be used with good effect on slabs. Joints should be covered and the blankets held down to prevent wind blowing underneath.

Photo courtesy of The Delta Company

confine this heat. Generally speaking, their effectiveness varies in direct proportion to their cost. They range from just leaving the forms in place to elaborate setups in which protective shelters are built and steam heated. In the simpler methods, there is much dependence on the "built-in" heat of the concrete. More expensive protection relies upon artificial heat.

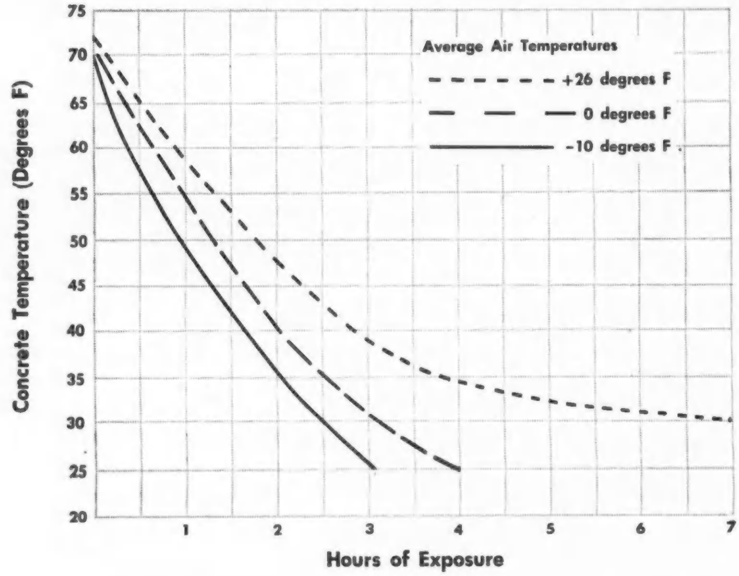
A recent survey of concrete contractors determined that concreting costs average 8 to 10 percent higher in winter than in summer. If your winter costs are exceeding this rate, perhaps the following evaluation of some of the major protective coverings will prove of interest.

WOOD FORMS

Ordinary wood forms offer some insulating value. Steel forms, on the other hand, are at a disadvantage in cold weather since they are such excellent conductors of heat. Wood forms thicker than standard offer somewhat greater insulating protection but not enough to justify the increased cost. Most effective practical protection possible with wood forms is provided by two ⅞-inch boards with 1 inch of dead air space between. Air circulation in the space must be kept to a minimum or its insulating value will be greatly reduced. A tarpaulin might be needed at the corners and edges to prevent freezing.

STRAW

Straw, by itself, is not sufficiently air-proof to act as an efficient thermal insulator; but, when used in conjunc-



The curves in this graph show the rate at which the temperature of concrete drops at various average air temperatures.

tion with other materials, it often is useful. It is low-cost and serviceable during relatively mild weather, although not as effective as commercial form insulation. It should be covered with a sheet material, such as tarpaulins, when used on flat work. Care is necessary to avoid marring surfaces with the rough straw.

PLASTIC SHEETS

Plastic and polyethylene sheets, building paper, sisalkraft, tar paper and like materials can prove helpful at temperatures down to 18 degrees. They are low-cost, lightweight and flexible enough to meet the demands of unusually-shaped enclosures. They are especially effective when laid so that a small dead air space is left between them and the concrete. Being relatively thin, they should be carefully anchored.

FORM INSULATION

With the advent of improved, more rugged backing, form insulation is finding an increasing group of users. This material is easy to apply, can be reused often and, in conjunction with wood forms, provides fine thermal insulation. It is especially good in applications where one side of a slab is to be heated and the other side protected; e.g., a floor slab when the floor below is enclosed and heated but the story above is not. On vertical work, where forms are needed on all sides of the concrete, a problem is created in very cold weather. Since commonly-encountered building sections are usually not of great enough mass to generate sufficient heat for the complete curing period, it is necessary to introduce heat. However, the poor heat conducting characteristic of wood forms works contrary to the contractor in this case because it would take an impractical amount of heat to raise the temperature of the concrete within the forms. (Metal forms, of course, have a marked advantage under these circumstances.) A possible solution might be to employ electric heating, by means of an alternating current passed through the cement paste. Cost of this method has run as low as 7 percent over summer concreting cost. On massive work, this problem is not encountered. (MORE)

Spread on the ground, anchored at the edges with sandbags, and pumped full of warm air, this giant bubble of polyethylene film made it possible to pour an entire concrete foundation in subfreezing weather.

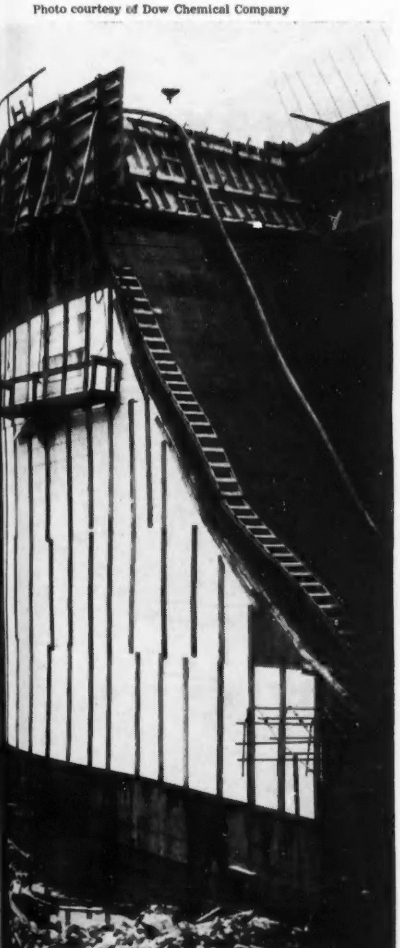
Photo courtesy of Visking Company

ENCLOSURES

Enclosures are probably the most effective means of protecting concrete during winter—also the most expensive. They stop the wind, keep out the cold and keep in the heat. They are generally used with artificial heat, either dry (salamanders) or wet (steam). Although steam heating provides an ideal curing environment, it is unfortunately far from ideal for workmen. Openings in enclosures should be kept to a minimum and, where necessary, they should have easily worked coverings. Enclosures made with flexible materials are lower in cost, and easy and fast to build and tear down. Enclosures built with rigid materials are more effective in blocking wind and keeping perimeter temperatures up. They provide simply-operated coverings for openings and require less attention to keep them windproof. END

Rigid plastic foam insulation used to protect a concrete dam from rapid temperature changes.

Photo courtesy of Dow Chemical Company



INSULATION EQUIVALENTS

1 inch of insulating material	Equivalent thickness, inches
Commercial blanket or batt insulation	1.000
Loose fill insulation of fibrous type	1.000
Insulating board	0.758
Sawdust	0.610
Lumber (nominal)	0.333
Dead-air space (vertical)	0.234
Damp sand	0.023

This table shows the insulation equivalents of some of the materials that are used for winter protection of concrete. It indicates that it would take about 4 feet of sand to provide the same protection as 1 inch of commercial insulation.

INSULATION REQUIREMENTS FOR CONCRETE WALLS AND FLOOR SLABS ABOVE GROUND

Concrete placed at 50 F

Wall thickness, feet	Minimum air temperature allowable for these thicknesses of commercial blanket or batt insulation, degrees F.			
	0.5 inches	1.0 inches	1.5 inches	2.0 inches
Cement content—300 pounds per cubic yard				
0.5	47	41	33	28
1.0	41	29	17	5
1.5	35	19	0	−17
2.0	34	14	−9	−29
3.0	31	8	−15	−35
4.0	30	6	−18	−39
5.0	30	5	−21	−43
Cement content—400 pounds per cubic yard				
0.5	46	38	28	21
1.0	38	22	6	−11
1.5	31	8	−16	−39
2.0	28	2	−26	−53
3.0	25	−6	−36	
4.0	23	−8	−41	
5.0	23	−10	−45	
Cement content—500 pounds per cubic yard				
0.5	45	35	22	14
1.0	35	15	−5	−26
1.5	27	−3	−33	−65
2.0	23	−10	−50	
3.0	18	−20		
4.0	17	−23		
5.0	16	−25		
Cement content—600 pounds per cubic yard				
0.5	44	32	16	6
1.0	32	8	−16	−41
1.5	21	−14	−50	−89
2.0	18	−22		
3.0	12	−34		
4.0	11	−38		
5.0	10	−40		

This photomicrograph, which also appears on the cover, shows how bubbles of entrained air provide flexible ball bearings between mix particles.

Even the experts can't agree, but here are some principles of concrete technology that have emerged from efforts to minimize the disruptive effects of successive cycles of freezing and thawing.

Photo courtesy of Dewey and Almy Chemical Co.

CONCRETE VS FREEZING-THAWING

The two specimens of concrete pictured below are identical except for the inclusion of entrained air in the one shown in the bottom photo. After 150 cycles of freezing and thawing under water, the non-air-entrained specimen is in an advanced state of disintegration while the air-entrained specimen shows almost no signs of distress.

Photo courtesy of The Master Builders Co.

"Don't let uncured concrete freeze."
"If it's going to freeze,
let it happen early."
"The later it freezes, the better."
"It doesn't matter if it freezes."
Confusing, isn't it?

TRY READING the various reports of freezing-thawing tests made on concrete. It can be rather like conducting a pre-season survey of baseball pennant winner predictions. There doesn't seem to be much agreement. Even the most unlikely prospects have avid partisans.

In Russia, freshly-poured concrete has been intentionally allowed to freeze and remain frozen until the spring, whereupon it thawed and cured. Subsequent tests showed concrete strengths to be satisfactory. Another Russian view is that concrete frozen directly after mixing attains (after thawing and curing) less than one-half the strength of the same mix that had not been subjected to freezing.

Agreement exists on some points, however. It is the action of ice crystals compressing unfrozen water that has the disruptive effect on the structure of concrete. The great increase in bulk in the transition from water to ice literally causes an explosion by forcing water at great pressures against the hardened cement paste.

Several test findings agree that frozen concrete is quite porous and therefore is likely to deteriorate seriously during subsequent freezing-thawing cycles. In addition, it seems the longer it is initially frozen, the greater will be its porosity.

If the concrete is still plastic when freezing occurs it can more easily "give" to allow for the expansion; but once the concrete has set, it is generally agreed that strength is directly proportional to curing time. Cylinders made with Type II cement and containing 4 percent entrained air were given a preliminary five days curing at 50 degrees, frozen three days at 10 degrees and subsequently moist stored at 50 degrees. They proved to suffer a reduction of 28-day strength of 7 percent. Identical cylinders that had seven days preliminary curing showed no reduction in strength.

Cylinders that were similar except for the use of Type V cement produced different results, however. These cylinders showed a 13 percent reduction in 28-day strength regardless of whether the preliminary curing period had been three, five, or seven days. Obviously, cement type also enters into the question.

The rate of strength increase is accelerated by providing a plentiful supply of water for the hydration of the thawed concrete. Naturally, provision of this water causes some problems if there is any danger of a recurrence of freezing temperatures.

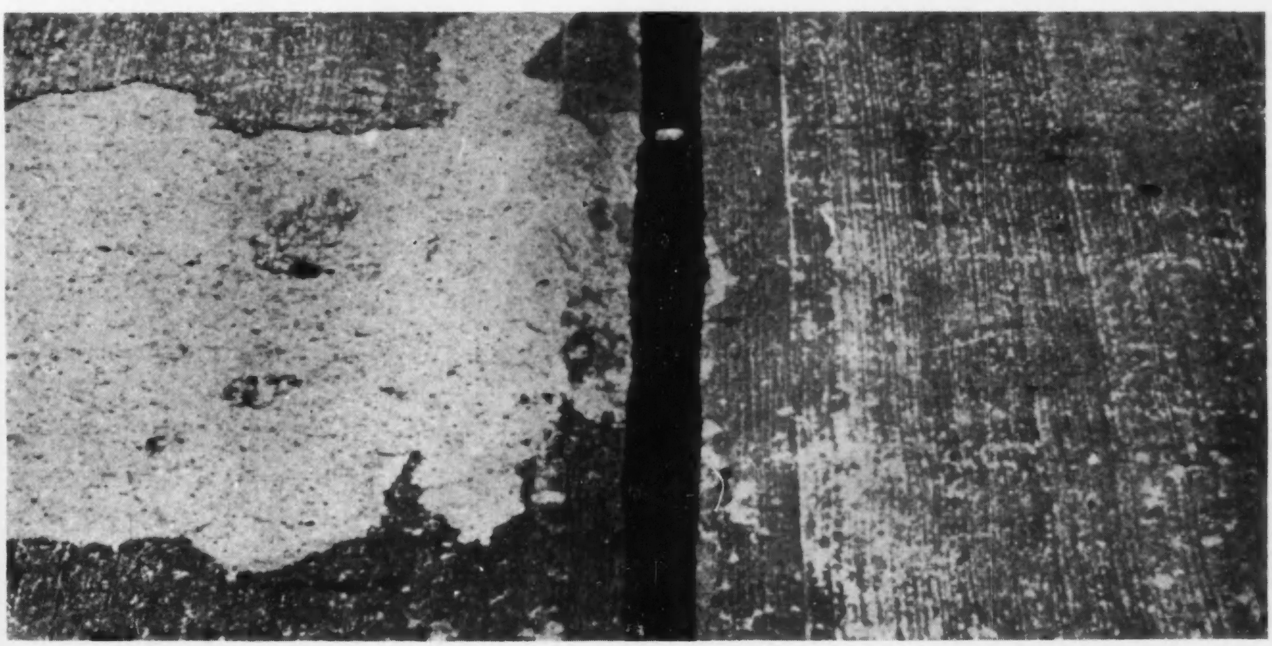
It's comforting to come upon a sure fact in a subject with so many unsubstantiated aspects. That sure fact is that the inclusion of an appropriate amount of entrained air materially increases the weathering ability of concrete. In every study made, whether in the laboratory or the field, this has been unmistakably apparent.

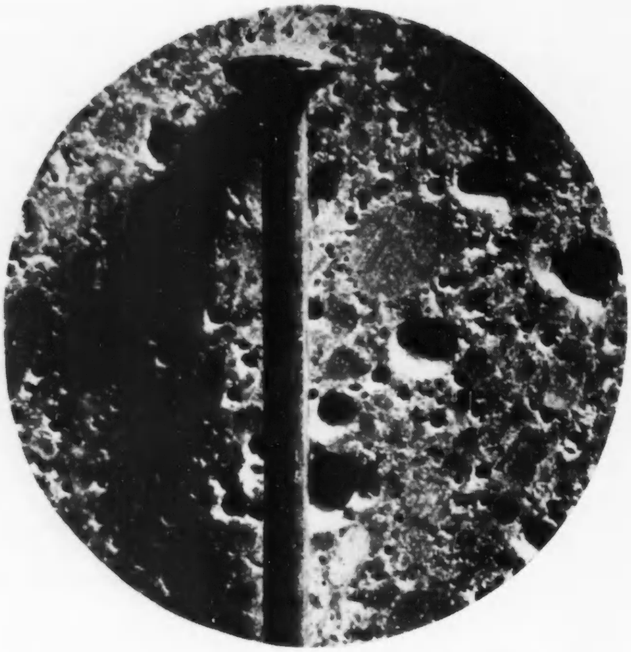
When the water in concrete solidifies it does so in an almost instantaneous surge producing tensile pressures as high as 30,000 psi. Since the tensile strength of concrete is generally well below 1,000 psi, it is apparent that severe damage can be caused. This is especially true since the permeability (resistance to water flow) of cement paste is extremely low. It takes a pressure of 40 psi per foot of thickness to force water through an average paste at the rate of only 1/10 of an inch per year!

The permeability of cement paste from its fresh state to 24 days age is reduced one billion-fold. Let's adopt an arbitrary unit and make some comparisons. Assume that the permeability of cured cement paste ranges from 1 to 70; then calcite would be rated 600 to 12,000; limestone 900 to 1,500,000; and face brick 3 million to 30 million.

Conversely, possible water absorption by cement pastes is quite high; it varies from 27 to 55 percent by

Graphic proof of the benefits of air entrainment is offered by this test pavement. Identical exposure has caused severe spalling in the non-air-entrained section at the left, but has not affected the air-entrained concrete at the right.





These pictures illustrate the effect of air-entrainment on concrete. A sample of air-entrained concrete is shown magnified in the top circle and non-air-entrained concrete is pictured at the bottom. An ordinary straight pin is included for scale. It is into these minute air cells that water is able to flow under pressure of ice crystals forming and thus relieve stress. There are billions of these cells in a single cubic foot. The great durability and increased resistance to scaling of air-entrained concrete is the reason it has been specified for all pavements by 36 state highway departments.

volume. In contrast the optimum absorption of calcite and limestone is ¼ to 17, and that of face brick is 14.

This combination of high absorption capability and low permeability can produce a water soaked mass with no allowance for the expansion that is an inescapable partner of freezing water. As a result, ordinary water-soaked cement paste deteriorates under freezing-thawing cycles.

To get around this damaging effect researchers have come up with air entrainment. The accompanying photographs show magnified cross-sections of a concrete sample containing entrained air and one substantially without air. The average bubble-to-bubble distance in concrete containing 3 percent air is not more than 1/100 of an inch. In effect, this divides the paste into thin layers. Then, when freezing and expansion occur, there is room into which unfrozen water being compressed by the ice crystals can flow without destroying the structure of the paste.

Another important and verified element in freezing-thawing damage is the question of aggregate soundness. Air entrainment protects the cement paste but it cannot effectively control expansion in the aggregates. If aggregates of high porosity are used, they will expand upon freezing and the same disruptive effect upon the structure will take place. Most porous aggregates also rate poorly in abrasion resistance—the one quality for which the cement paste is dependent upon the aggregates. All in all, selection of aggregates is a prime consideration in the goal of producing lasting concrete.

It has been stated that cement paste has a great capacity to hold water, the ultimate culprit in our freezing-thawing problem. If, however, the paste is produced so that a minimum amount of water is used, there will be less likelihood of freezing damage. Aggregate expansion is also kept to a minimum because the dry paste reduces the water saturation of the aggregate.

Summing up, there is disagreement on many aspects of the freezing-thawing problem; but practical experience has shown that if the following points are adhered to, concrete work will stand up well under the effects of weathering: (1) use a well-balanced, rich concrete mix; (2) entrain air; (3) use only sound aggregates; and (4) protect the concrete until it has gained sufficient strength to withstand freezing and thawing. END